Standing Balance Control for Tsinghua Hephaestus

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Abstract: This paper presents an upper body balance control system. Balance keeping and upper body posture maintenance are two essential functions for the adaptation of a humanoid robot on an uneven surface. The posture of the inclined surface is considered as additional degree-of-freedoms. Utilization of the null-space approach requires the current full kinematical state of the even surface. However, the challenge is that the inclination of the surface can be arbitrary and unknown. For this reason, a flywheel inverted pendulum based on the center of mass null space is proposed, then cascade control on the gait planning of the divergent component of motion. This control framework is validated by using a position-controlled humanoid robot Tsinghua Hephaestus. The experimental results demonstrate an excellent dynamic response, showing the effectiveness of the upper body balance control system.

Keywords: Divergent Component of Motion, Upper Body Balance Control, Flywheel Inverted Pendulum.

1 Introduction

For the common interaction strategy of the robot's contact with the ground, it is necessary to control the robot's upper body posture and center of mass (CoM) position at the same time, so that it can adapt to global uneven terrain changes. For this reason, it is called upper body balance control, not upper-body posture control. This study used the modular design on the control system, so it can independently design the upper body balance control system. Because in fact, the changing source of the center of pressure (CoP) may not be only from uneven terrain but also from the upper body contact force acting on the robot. At that time, it is hard to distinguish whether the CoP error caused by uneven terrain or other contact force. Therefore, this research only used the data from the inertial measurement unit (IMU) and joint encoders, so that the control algorithm will not conflict with other algorithms which using the force sensor on the sole.

Research on upper body balance control using an inverted pendulum model has been implemented on some robots, such as COMAN of IIT and SUBO of KAIST[1-4]. The main difference between this study and the above literature is that in order to design the control system based on the modular design, the measured CoP point cannot be used as part of control algorithm. Therefore, this study proposes a flywheel

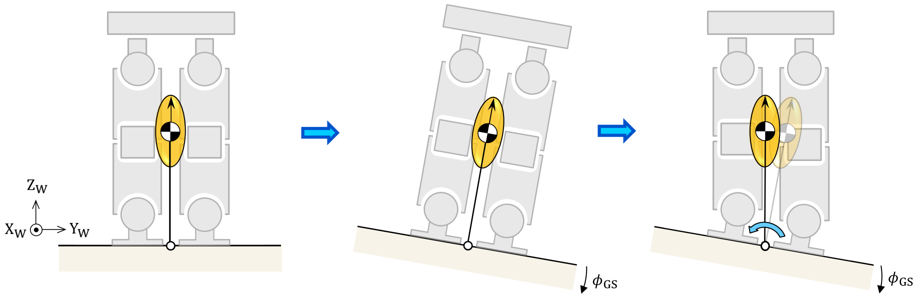

Fig. 1. Upper body balance control standing in place.

inverted pendulum model based on CoM null space as shown in Fig. 1. The flywheel attitude corresponds to the waist attitude of the robot, which mounted IMU.

2 Flywheel Inverted Pendulum Model

Perform the CoM null space analysis on flywheel inverted pendulum model, and set the ground to be an inclined plane with unknown angle disturbance, which rotation axis is in the middle of two feet as shown in Fig. 2. In this figure, $X_W Y_W Z_W$ represents world coordinate system, α_1, α_2 are uncontrollable angles in the work space, β_1, β_2 are controllable angles in the joint space, and ϕ_{GS} is an uncontrollable angle in the joint space. Although the slope change angle ϕ_{GS} is an unknown disturbance input from the global terrain, it can be estimated through calculation of forward kinematics by the angle α_2 which measured by the IMU. Therefore, the joint space input by the system is three degrees of freedom $\phi_{GS}, \beta_1, \beta_2$, and the working space output by the system is two degrees of freedom α_1, α_2.

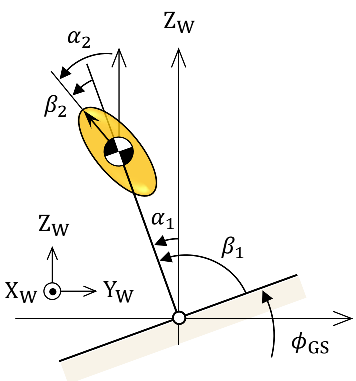

Fig. 2. CoM null space analysis.

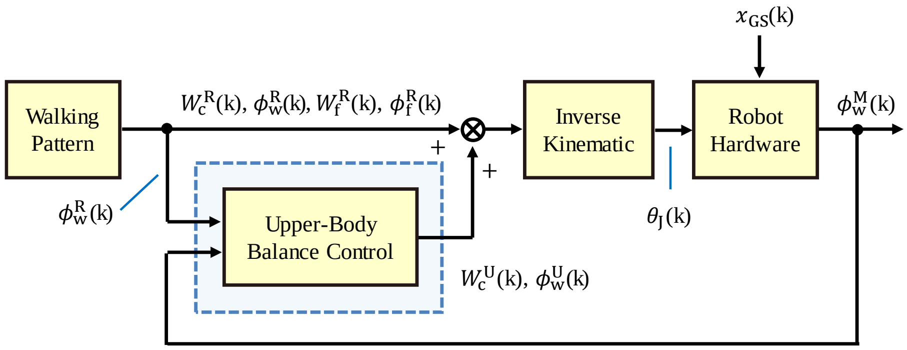

Fig. 3. Upper body balance control basic framework.

3 Control Framework

According to the proposed flywheel inverted pendulum model, the upper body balance control framework is designed. Since the motion of the inverted pendulum is symmetrical in the X-axis degrees of freedom ϕ and Y-axis degree of freedom θ, and they are decoupled from each other during control, thus the X-axis degree of freedom ϕ are used below to describe the control framework as shown in Fig. 3. The walking pattern generate the CoM trajectory W_c^R, supporting and swinging feet trajectory W_f^R, waist attitude ϕ_w^R, and the attitude of both feet ϕ_f^R. The planning waist attitude ϕ_w^R and feedback IMU state ϕ_w^M are the input of upper body balance control system. Through the algorithm, the control output W_c^U, ϕ_w^U add to the reference trajectory and attitude of walking pattern. Then, the inverse kinematics is used to calculate the joint angle θ_J of the robot, which is input to the position control motor.

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